ESRC ECONOMIC AND SOCIAL RESEARCH COUNCIL

INFORMATION TECHNOLOGY AND EDUCATION PROGRAMME

Occasional Paper
ITE/29/88



# Learner's Concepts in Mathematics and Science

July 1988



Edited by Professor Philip Levy
Department of Psychology
University of Lancaster

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# Origins of the ESRC INFORMATION TECHNOLOGY AND EDUCATION PROGRAMME

The Education and Human Development Committee was established with the reorganisation of the then Social Science Research Council in May 1982. In 1984 the Council changed its name to the Economic and Social Research Council. Early in 1983 the Committee identified and circulated for discussion an initial listing of important topics which warranted expanded support or accelerated development. The broad area of Information Technology in Education occupied a prominent place in that list The Committee emphasised its intention that research would be centred not only on the effect on education of machines to help teach the existing curriculum. but on the development and adaptation of the curriculum to equip people, including those of school age, to deal with intelligent machines and to prepare them for a life changed by their arrival. For example, there are questions concerning both cognitive and organisational factors which facilitate or inhibit the adoption of Information Technology in Education, and allied to these, questions around the nature, characteristics and development of information technology literacy.

Two reports were commissioned and detailed discussion and workshops were held in 1983. In its further considerations, the Committee was conscious of the fact that the research community is widely scattered and has relatively few large groups of researchers. Furthermore, it recognised the importance of involving practitioners and policy makers in the development of its programme of substantive research and research related activities and the necessity of ensuring close collaboration with commercial organisations such as publishers, software houses and hardware manufacturers. It was this thinking that led the Committee away from the establishment of a single new centre to the appointment of a coordinator over the period 1985 – 88, as the focal point for the development of the initiative throughout the country.

The brief for the Coordinator included:

- the review, evaluation and dissemination of the recent and current activity in the field of Information Technology and Education;
- the identification of the needs of education in relation to Information Technology;
- the stimulation of relevant research and the formulation of research guidelines;
- the establishment and maintenance of a database of relevant work and undertaking arrangements for coordinating and networking of those active in the field including cognitive scientists, educational researchers, practitioners and policymakers.

In January 1988, the Council of ESRC approved a new initiative which would have resources to support a substantive research programme This programme, the Information Technology in Education Research Programme, gets under way in the autumn of 1988. A new series of InTER Programme Occasional Papers will begin to appear in a similar format to the current ITE Programme series. The latter are listed on the back cover of this paper.

# Learner's Concepts in Mathematics and Science

## PREFACE

It has been an important task for the Programme to identify an agenda for research on the roles and uses of information technology in education. Many of the seminars conducted within the Programme have reviewed the state of the art and research in progress. In December 1987, a weekend seminar was held in Sheffield to develop issues for future research in an important curriculum area – science and mathematics. About twenty leading educationalists and psychologists were invited to participate. This Occasional Paper publishes the invited contributions along with rapporteurs' comments and reflections upon the ensuing discussions.

The problems of maths and science education have long attracted much attention. In part, this has been due to national concerns with 'trained manpower needs' or with 'education for a technological society'. In part, however, the strong research focus on maths and science – rather than upon some other areas of the curriculum – may have been sustained by the illusory ease with which the maths and science curricula may be specified and the misleading facility with which the 'right conceptions' or the 'right answers' may be defined. Surely these explicit goals can be achieved with greater efficiency using the 'right methods'? This rhetorical question roughly indicates the style of much past research.

Similarly, the Piagetian focus upon the emergence of logical (mental) structures and the development of conceptions of the physical world may have exaggerated the rationality and coherence of the outcomes even in highly skilled adults let alone the typical secondary school pupil.

The discussions in the seminar started further along the track. Given that pupils have 'naive conceptions': What is their nature? Are they not functional in some sense? How do transitions occur? Cannot several conceptions usefully co-exist?

Suppose that we had a clear view of how children learn: How does the system, within which learning is supposed to take place, operate? How does curriculum change proceed? What are the implications for classrooms? How have teachers responded to past 'innovations'? What is the role of 'instruction', of 'direct experience', of simulation, and so on? These are familiar questions. From these beginnings, the discussions increasingly emphasised a number of common points. Human knowledge is always to some degree 'context bound'. Disembedding knowledge is sometimes functional and sometimes not. Knowledge is shared and transmitted and exercised through discourse, including discourse with oneself. Mathematical and scientific knowledge – the understandings, the symbol systems and the problems to be solved – are as much 'social' and 'societal' and 'discursive' in character as any other area of knowledge. What are the implications of this style of analysis for maths and science education? What roles might information technology play in this scenario? How might the research questions about maths and science education be revised? Now read on!

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# The Nature of Pupils' Naive Conceptions in Science

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## INTRODUCTION

An extensive literature has been built up in recent years which indicates that children develop ideas about natural phenomena before they are taught science in school.* In some instances these notions (variously described as preconceptions, misconceptions, intuitions, alternative conceptions, alternative frameworks, naive theories or spontaneous reasoning) are in keeping with accepted scientific ideas. In many cases, however, there may be significant differences between children's notions and school science.

Surveys undertaken in various countries have identified commonalities in children's ideas, and developmental studies are giving insights into the characteristic ways in which these ideas progress during the childhood years (Carey, 1985; Strauss and Stavy, 1982). In-depth investigations have indicated that such ideas are to be seen as more than simply pieces of misinformation; children have ways of construeing phenomena which differ substantially from school science and which they may continue to use into adulthood despite formal teaching.

Currently, research on children's ideas is being interpreted within a cognitive perspective (Carey, 1986). A key feature of this interpretation is the notion that human beings understand situations in their world (whether text, dialogue or events) in terms of 'mental representations'. Moreover as suggested by Bereiter (1985) "a core belief in contemporary approaches to learning is that knowledge and cognitive strategies are actively constructed by the learner". Learning is seen as an active process whereby the learner relates existing 'mental representations' to new situations in order to construct meaning. The meaning that is constructed thus depends on both the situation and the 'representations' the learner has available. Thus, from an educational point of view, an understanding of children's ideas prior to teaching has been seen to be important because of the influence these have on subsequent learning.

Furthermore, studies of children's reasoning about natural phenomena suggest that these mental representations tend to be specific to particular content domains. As Rumelhart and Norman (1981) argue: "Our ability to reason and use our knowledge appears to depend strongly on the context in which the knowledge is acquired. Most of the reasoning we do apparently does not involve the application of general purpose reasoning skills. Rather it seems that most of our reasoning ability is tied to particular bodies of knowledge."

In this short paper I will attempt to give a flavour of the research on children's ideas about natural phenomena in a number of domains. One well researched area, that of force and motion, is reported in greater detail than others in order to give some indication of the range of data collection methods being used. A number of general characteristics of children's ideas about natural phenomena are then outlined and finally some issues for research and practice are identified.

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* Reviews, collections of papers and bibliographies can be found in Pfundt and Duit, 1985; Jung et al, 1982; Helm and Novak, 1983; Driver and Erickson, 1983, Gilbert and Watts, 1983; Driver, Guesne and Tiberghien, 1985.

## SPONTANEOUS REASONING ABOUT FORCE AND MOTION

There are a number of features which characterise spontaneous reasoning in this domain.

*The force of moving objects:*

An intuitive association between force and motion has been found to be most pervasive in the thinking of both children and adults. People tend to associate a force with any moving object; this force is what keeps the object moving. It may, however, get used up as when an object such as a freewheeling bicycle slows down and stops. When asked "What makes a ball rolling along the floor eventually stop?" an 11 year old said:"I don't know – why do they stop? – it's just that they always stop. After you push it they go as far as the push – how hard it was – and after that wears off it just goes back like it used to be."

In probing the pervasiveness of this notion, Watts and Zylbersztajn (1981) undertook a survey of 14 year old English school students' ideas about force and motion. They set a number of questions relating to the forces on a cannon ball in flight. Most of the students (about 85%) selected answers in which the force was associated with the direction of motion of the cannon ball.

In a seminal study in this area Viennot (1979) presented French, Belgian and British secondary and University students with a number of written questions concerning motion. In one of the questions six juggler's balls are drawn at the same height above the ground but at different points on their trajectories. A common feature in the students' answers was that the forces on the balls would be different because their velocities are different.

The converse of the rule that motion implies a force is of course that if there is no force there will be no motion. McCloskey (1983) reports a series of investigations in which he and his collaborators probed students' "knowledge-in-action". University physics and non-physics students were asked to release a ball from their hand while moving across the floor so that the ball hits a target marked on the floor. The number of students releasing the ball before, over and after reaching the target was noted. The results indicated that the majority of students released the ball directly over the target suggesting that they may be neglecting the horizontal component of the motion of the ball or implicitly assuming it will be zero as soon as it leaves their hand.

A further feature of spontaneous reasoning in this area is that objects go in the direction they are pushed. Di Sessa (1982) reports a study of students' interactions with a computer game called dynaturtle: an object on a screen, the dynaturtle, obeys Newtonian laws of motion, in that it remains at rest or moves in a straight line when no force is acting on it. It can, however, be given a 'kick', of varying magnitude and direction. When asked to move the dynaturtle on the screen so as to strike a target, a popular strategy used by students is to ignore the initial motion of the turtle and direct the kick straight at the target (the expectation being that the turtle will move in the direction of the kick).

*Objects at rest:*

The association between the spontaneous ideas of force and motion emerges when students are asked to consider objects at rest on a surface. In discussing the case of a book resting on a table, for example, students acknowledge the existence of a

downward force due to the weight of the book. ("If the table were not there, the book would fall down.") However, they tend not to identify the table as exerting an upward force on the book ("How can it if it can't move?") (Clement, 1983; Minstrell, 1982).

*Weight, gravity and trajectories:*

Students' notions about weight and gravity have also been explored. Heavier things are seen as falling faster than lighter things (Gunstone and White, 1981; Watts, 1982). Furthermore, gravity and falling is often associated with air and the atmosphere. When asked to predict the path of a projectile thrown in a vacuum many Norwegian school and University students predicted the path would be a straight line, rather than the usual parabolic path because "gravity needs a medium" (Sjoberg and Lie, 1981).

The pervasive notion that "motion implies a force" has been identified in the responses of school and University physics students to a range of mechanics problems, including projectile motion and circular motion. Parallels have also been drawn between students' ideas and ideas such as 'impetus theory' in the history of science (McCloskey, 1983), although such parallels need to be interpreted with caution.

## SPONTANEOUS REASONING IN OTHER DOMAINS OF EXPERIENCE

*Matter and substance:*

Children's ideas about matter and substance have been investigated from a number of perspectives. When a substance undergoes a simple transformation, such as sugar dissolving in water, young children tend to think that the sugar disappears. Later they acknowledge that the sugar is still there even though it cannot be seen; however, it may be considered to be weightless and not to occupy space (Holding, 1987). When a substance burns or corrodes matter is also believed to disappear ("it burns up – leaving only ash – a part which does not burn"). Older children, however, construe the continued existence of matter even when it cannot be perceived directly. They also begin to consider matter as being composed of discrete 'bits' which can be dispersed and brought together again. These 'bits', however, tend to be seen as having the characteristic properties of the substance itself (eg. they can expand on heating, melt or burn) and do not therefore represent a scientific atomistic view (Brook and Driver, 1984).

*Light and sound:*

In the domain of light and vision (Guesne, 1985) young children see light only as a source (an electric light bulb, the sun) or an effect (a bright patch on the wall). They do not consider light as existing in space or travelling out from the source. Children first construe light as travelling when they consider luminous objects. These are thought of as giving out light, but the light can only travel a certain distance before it loses its strength; light is also considered to travel further at night when it is dark than in the daytime. The connection children make between light and sight is indirect, with notions of visual rays from the eye to an illuminated object sometimes being used to explain vision.

*Heat and temperature:*

Children tend to reason about phenomena in which objects or substances are heated in terms of heat as a quasi-substance (Erickson, 1979, 1980) which 'flows

though', 'spreads out' and 'fills up' objects. 'Hot' and 'cold' may even be seen as distinct. Temperature is seen as a property of different substances with, for example, metals being identified as naturally colder than other materials such as wood or plastic.

An interesting series of investigations has been undertaken by Strauss and Stavy (1981) into the development of children's understanding of temperature. They document a U-shaped developmental pattern in responses of children aged 4-13 as they differentiate the notion of temperature as an intrinsic property of substance from the amount of substance present. Parallels have also been drawn in this area between children's spontaneous reasoning and historical developments in this field of science (Wiser and Carey, 1983).

Spontaneous reasoning in a range of other areas has been investigated including electric circuits (Shipstone, 1985), the Earth in space (Nussbaum, 1985), air and air pressure (Sere, 1985), energy (Solomon, 1982; Watts, 1983), plant nutrition (Bell, 1985), inheritance (Engel-Clough and Wood-Robinson, 1985).

## GENERAL FEATURES OF STUDENTS' CONCEPTIONS IN SCIENCE

*Commonly occurring ideas:*

It appears from the research that humans do develop conceptions about a range of natural phenomena independently of formal instruction. Similarities in the conceptions used by children in different countries and from different social backgrounds have been noted and have promoted speculation about origins. Regularities in children's experiences with physical phenomena have been suggested as a contributory factor as has the 'shaping' of childrens' conceptions through everyday language and metaphor.

*Coherence of children's ideas:*

Although they may differ from currently accepted ideas in science, children's conceptions are coherent with a limited range of experiences and in this way can be seen to 'make sense'. In the area of mechanics, for example, the notion that the force in a moving object gets used up is well adapted to a world with friction. Recognising the extent to which children's ideas do fit with their experience has important implications for educators. Children may not necessarily appreciate the need to change their models as a result of teaching when the ones they hold seem to work effectively. This may account for the extent to which ideas in certain domains in particular tend to persist despite instruction and we find undergraduate science students still using certain 'spontaneous' notions in solving mechanics or electrical problems.

The notion, suggested by Solomon (1983), that pupils may use different conceptions in different domains of experience with 'life-world' and 'school science' being distinct may also account for the persistence of naive conceptions.

*Context specific reasoning:*

Conceptions pupils use in making predictions and explaining events appear to be influenced by various contextual features. The extent to which pupils use consistent models varies across domains of experience. In general, however, pupils may use quite different ideas in response to situations which are seen as similar from a scientific point of view (Engel-Clough and Driver, 1986). In open problem solving situations in classrooms, pupils can be seen to draw on and try out a range

of possible ways of modelling a situation each of which is against the evidence for its 'fit'. Models are thus being drawn on and checked in a dynamic way in practical situations. Matters of interest here include how this interfacing between a pupils' available models and the presented situation occurs, and how decisions are made by learners as to which available models may be appropriate in specific situations.

*Progression in pupils' conceptions:*

Studies of pupils' ideas in selected domains during school years indicate the ways naive conceptions may change as children get older. A dominant perspective is that these changes involve radical restructuring of pupils' conceptions (Carey, 1985). The changes in pupils' ideas about light described earlier can be seen as an example of how progressively more complex entities are construed to account for perceived phenomena. Young children seem to have no notion of light existing in space; as they get older we see first the notion of a 'bath' of light and then the notion of light as 'travelling' being incorporated into their conceptions.

Although we know that these kinds of changes take place, the mechanisms which underlie the changes are not well understood. Indeed this is an area of current research interest in science education.

It might be tempting to view science education as a process whereby pupils' naive conceptions are gradually and progressively shaped towards those of school science. Such a view, however, would also need to take account of the important differences which exist between 'everyday reasoning' about phenomena and the scientific pursuit. In 'everyday reasoning' the criterion for acceptability of a particular model tends to be utilitarian (does it help in getting the electrical gadget working, find the fault in the car engine, etc.); whereas within science the criteria of coherence and parsimony are more influential. There are also important differences between what is meant by explanation in pupils' reasoning and that which is used in science. For pupils, an explanation is often seen in terms of a linear sequence of events in time rather than involving a modelling process. These are some of the reasons why it may be simplistic to view school science learning as a continuous process of conceptual 'evolution'. There may be important discontinuities which need to be recognised between the kind of reasoning used in everyday situations (to which naive conceptions are adapted) and the formal pursuit of science.

*Personal or social construction of conceptions:*

The perspective which derives from a Piagetian tradition is that knowledge of the world comes about through the individual's spontaneous interaction with the physical environment. This perspective is clearly presented by Strauss (1981) who, in accounting for commonalities in naive conceptions, argues:

> "the common-sense representation of qualitative empirical regularities is tied to complex interactions between the sensory system, the environment that supplied the information ... and the mental structures through which we organise the sensory information which guides our behaviours. I argue that individuals' common-sense knowledge about qualitative physical concepts is no different today than in the times of, say, Aristotle."

An alternative perspective places greater emphasis on the social transmission and construction of knowledge (Solomon, 1987). From this social perspective it is argued that the mental models which are used to organise experience are culturally transmitted. (The conceptual environment in which humans live in the twentieth century differs considerably from that of Aristotle!) If science itself as public knowledge is socially constructed, then learning science must be seen in terms of a process of social transmission.

Edwards and Mercer (1987) argue this point:

> "However active a part pupils are allowed to play in their learning, we cannot assume that they simply reinstate that culture through their own activity and experience. It necessarily a social and communicative process and one which has as an inherent part of it an asymmetry of roles between teacher and learner."

EDUCATIONAL IMPLICATIONS

If it is accepted that learning in science involves the re-structuring of students' conceptions, then understanding the processes by which conceptual change occurs becomes a central issue for educators.

Drawing on accounts of the history of science, Posner et al., (1982) suggest that a number of conditions need to be met if conceptual change is to take place. First there needs to be dissatisfaction with existing conceptions, then a new conception must appear intelligible, plausible and fruitful in offering new interpretations. It has also been suggested that conceptual change can be potentially threatening to the individual (Claxton, 1984) and that students may require a supportive environment where each individual's ideas are valued if new ways of thinking are to be explored.

Ways of promoting conceptual change in classrooms have been investigated by a number of research groups. (Champagne et al., 1982, Driver and Oldham, 1986; Hewson and Hewson, 1984; Nussbaum and Novick, 1984, Osborne and Freyberg, 1985). The types of teaching strategies which have been suggested as facilitating conceptual change include:

(i) providing opportunities for pupils to make their own conceptions about the topic explicit so that they are available for inspection;

(ii) presenting examples which challenge children's prior ideas. Counter examples themselves do not provide children with new conceptions. They may, however, provoke children into considering the need to rethink their ideas. Children use various strategies to avoid conflicts – they may select and fit observations to their existing ideas or argue that the counter example is a special case;

(iii) using strategies which enable pupils to consider and evaluate alternative conceptions of presented phenomena;

(iv) providing opportunities to use new conceptions. Long term accommodation of a person's conceptions is not likely to happen if new schemas are not seen as useful;

(v) giving pupils opportunities to become aware of their own conceptions and how they change. The effectiveness of various techniques for developing pupils' metacognitive strategies have been studies including concept mapping, and the use by pupils of personal learning logs.

A conceptual change view of learning also has implications for longer term curriculum planning in science. Developmental studies in specific domains show how children's schemas are restructured progressively over periods of years. This has implications for the long term organisation of learning experiences over the schools years.

How to give an adequate description of the conceptual change process and the mechanisms of change, however, still remains an open question, and an important area for inquiry.

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## Mathematical Education, Research and Information Technology

*Hugh Burkhardt, Shell Centre for Mathematics Education, University of Nottingham*

To start I will present a view of the situation in Mathematical Education. Then, I take a brief look at Information Technology's (IT) contribution to thinking in mathematical education, both at a fundamental and a curriculum level. Finally, the contribution that IT can make through research to advancing mathematical education is sketched.

### LEVELS OF RESEARCH

Education is an applied - 'an engineering' - discipline, where a 'systems' approach is appropriate (Burkhardt, et al., 1987). The system is 'teachers teaching children, in classrooms, in schools, in society'. Various levels of research are needed. I find it useful to distinguish.

*L-level*: studies of learning, conceptions and misconceptions (minimum $10^1$ children). Here we have developed:

- a detailed picture of some areas, eg. what proportion of 11-15 year old students can do a wide range of short technical tasks (see, eg. Centre for the Study of Mathematics and Science (CSMS). Assessment of Performance Unit (APU)).
- some models which explain these patterns (King's College London, Nottingham, ... BUGGY, Open University).

*T1-level*: teaching approaches ($10^2$ students). Here we have a variety of studies in recent years of strategies and errors, diagnostic teaching, LOGO, etc. (King's College London, Nottingham, Edinburgh, London, ....)

*T2-level*: realisable teaching ($10^3$ students). This level involves the study of teachers and teacher development in realistic contexts. Systematic study of teacher behaviour as part of research and curriculum development has been pioneered, particularly by the Investigation of Teaching using Microcomputers as an Aid (ITMA), in recent years; previously there has been a tendency to assume what one teacher could do, any teacher would do with a little encouragement.

*C-level*: large scale curriculum change ($10^4$ students up). Work on the dynamics of curriculum change is only just beginning to be taken seriously. Some retrospective analytical review has gone on for some time (Ontario Institute for Studies in Education (OISE)) but active empirical work has only recently begun (Nottingham, Lancaster). Developments in IT provide a particularly vivid illustration of the tendency of people to ignore the system realities in which they are working (eg. nearly all software and materials design is primarily aimed at a richly provisioned environment - a 100 micro school).

In general, previous research has concentrated very largely on *L* and *T1* levels. A more balanced approach is needed.

Theories in education of the traditional kind are ambitious but very weak in terms of their predictive power or the curriculum guidance they provide (Piaget, Bruner, Dienes, Skemp, Skinner,...). They are useful things to bear in mind but are more like 'effects' in the sciences than theories. It is emerging from the studies

referred to above, that much less ambitious and grandiose phenomenological analyses may, as in other fields, provide more power over the system. Some fundamental results, such as the importance of 'active processing' in learning, are powerful. The complementarity between phenomenological and fundamental studies, well understood in engineering say, has yet to be established in education (Ridgway, et al., 1988).

Information processing models of cognition are worth considering separately. A fertile source of ideas, most of the AI models and many others make no serious attempt to model actual cognitive processes and ignore empirical comparisons with human behaviour; those more recent attempts at accepting the constraints of physiological reality seem to have made limited progress so far. The knowledge based systems developed so far seem able to model very limited areas of knowledge in a useful and reliable way; how far they can be extended and at what cost is still unclear (Ridgway, 1988).

## SOME CONTRIBUTIONS OF IT

Fundamental elements of research in any field, are systems, probes and data capture - all guided by a purposeful, cost-effective design process. IT has contributions to make in all these domains, though it is ironical that the most obvious capture possibilities are perhaps the least useful (Burkhardt et al., 1987).

- Data capture in the study of educational systems has to be extremely selective because the amount of data available is so large. In education this implies 'front end processors' of considerable sophistication, if interesting questions are to be studied; computers are, of course, on the whole, not yet a match for humans in this role. They can, of course, provide secretarial and data storage support, as well as the tool kit of exploratory data analysis in the broad sense.

- The system defined above has been modified and developed to some extent by the introduction of IT devices and concepts. The dominant feature is the very great range of curriculum possibilities, so far hardly developed; there are mathematics tools, learning tools (such as microworlds of every size), teaching tools, and the new mathematics that computer technology and computer science have brought closer to centre stage.

- Probes are a domain in which IT has shown enormous possibilities in facilitating high quality research in mathematical education (Fraser et al., 1987; Burkhardt et al., 1988). We learn more about any system by perturbing it with a probe, than simply by observing it 'in equilibrium'. To be effective for this purpose, probes must be powerful and credible in the system context; nearly all the elements that IT has introduced into the curriculum have displayed this property. They change the learning and teaching situation in a powerful and controllable way - the perturbations are much more controllable that with other possible probes, such as new printed materials because of the potentially strong 'personaility' of the microcomputer. Technological devices have a 'finite state' quality in educational terms which is of help to the student, to the teacher and also to the researcher in providing tractible sub-systems for study.

Some key questions that need further investigation include (and this is merely the opening of a list, to be built upon in discussion, with at least one item at each level *L, T1, T2, C* above):

- How much personal manipulation (arithmetic, algebra, graphs, data, ...) is needed to establish robust conceptual understanding in an IT rich environment?
- Should the teaching of 'debugging' skills be a main force in all areas of mathematical education?
- In what ways can computers and other resources enhance the interpersonal dynamics of the classroom? (or of the company?)
- What are the effects on teaching and learning of having well-resourced classrooms with more students in them?
- How well do various approaches lead to large scale take-up of IT resources as worthwhile?
- ....

## THE SEARCH FOR BETTER METHODS

Compared with most fields, education is unusual in the very small anount of energy devoted to finding better methods whether of curriculum development, teacher training or research. An off-the-peg approach is the norm. The study of the dynamics of change and the search for better methods has been a main strand of the work of both the Investigation of Teaching using Microcomputers as an Aid and the Shell Centre for Mathematics Education at Nottingham for some years. We welcome this conference as another illustration of the awareness of this need in the IT-Education initiative.

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## Mathematics and Instruction: A Case for Research

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My interest in, and perspective on, research in mathematics learning and instruction arises out of three concerns. One is the study of mathematical abilities in deaf children. The second has to do with the theory of instruction with specific reference to how and when mathematics teaching should proceed. Thirdly, I am interested in the nature of pedagogical discourse and, more specifically in this context, in the nature of mathematical discourse. Let me say a little about each of these interests to help identify the research agenda they imply.

### MATHEMATICAL ERRORS AND MISCONCEPTIONS

Some years ago, we undertook a national survey of mathematical achievement in deaf school-leavers. This revealed that, whilst some three years behind the achievements of hearing peers, deaf children face many of the same problems and make similar errors to hearing children. Detailed item analyses of the test papers of both 500 deaf and 500 hearing children were undertaken in relation to a four-fold classification of error types. The proposed classification is:

*Mistakes:*
Performance failures not indicative of basic incompetence.

*Growth Errors:*
A species of error one might expect from novices prior to mastery of concepts and procedures.

*Entrenched Errors:*
Errors attributable to the incorporation of persistent growth errors within larger procedures.

*Misconceptions:*
Errors that betray fundamental confusion.

The errors we found resembled many already noted both in other surveys of mathematical achievement (eg Assessment of Performance Unit (APU)(DES 1980, 1982) and Centre for the Study of Mathematics and Science (CSMS) (Primary Survey Reports; Secondary Survey Reports)) and in experimental studies of children's 'buggy algorithms'. Whilst such errors and misconceptions are familiar to us, the issue of what *instructional* methods might be used to overcome them has yet to be resolved. Here, I will present my own general thoughts on the issue. These, of course, should not be viewed as 'the' definitive agenda but as specific examples of the species of research we might recommend.

The first thought is largely theoretical; different types of error demand different instructional intervention. Let me rehearse some of the arguments:

### MISTAKES

To err is human. To self-check and self-correct is intelligent. Children learning mathematics certainly meet the criterion for humanity but many fail the test of intelligence. Their mistakes, as many people have observed, often go uncorrected. What they lack, according to the theoretical framework I subscribe to, are skills in 'self-regulation'. There is some evidence that such skills can be *taught*. We need to see if they can be taught in relation to mathematics. One can envisage

several instructional strategies that might work, some of which could be formalised. A strategy I am currently evaluating is to see if children are able to diagnose other people's errors and, when they can, to see if practise in so doing transfers to their own self-regulatory activity in mathematical problem solving.

## GROWTH ERRORS

To the extent that children have an aptitude for mathematics and are able to monitor and self-correct, that are probably best left to their own devices. Evidence suggests that able children often develop their own, highly efficient and accurate solution procedures. 'Intrusive' instructional methods, particularly those demanding 'small step' teaching may inhibit such children's progress. However, where children find maths learning difficult, small-step, intrusive instruction seems of benefit.

For some years, we have been exploring the notion that instruction can be conceptualised in two, related ways. It implicates a number of 'scaffolding functions' which complement the limited information processing abilities of the learner and involves what we have termed the 'contingent control' of learning. To date, we have demonstrated the ability of such concepts in well-structured, relatively artificial domains. We are currently analysing video-taped recordings of maths lessons from this perspective. The results are far from encouraging. There is little evidence of scaffolding activity and instruction is seldom contingent. The issue we are faced with is whether one could ever expect 'traditional' group teaching methods to approach anything like optimum instructional techniques. If we decide that such an aspiration is doomed (even if we were able to identify and teach people how to scaffold contingently) we might fare better by trying to formalise the processes involved (is this theoretically possible?) and build them into intelligent tutoring systems.

## ENTRENCHED ERRORS

At least two main issues come to the fore here. First, are teachers able to diagnose children's 'entrenched errors'? For instance, we have found, as one might expect, that children showing specific problems with subtraction make predictable errors in long division. They possess relatively effective procedures for solving such problems but these call-up 'buggy algorithms' which in turn lead to predictable errors. Even if teachers are able to diagnose such errors (and I suspect many can), the issue remains as to whether they have the time and resources to do so. When feedback to learners is remote in time, they may well find themselves, so to speak, on a partial reinforcement schedule, since their solution procedures often produce what look like correct answers in some contexts. Here too, we may well need to explore ways and means of developing intelligent, diagnostic systems to assist teachers. We are currently designing such a system to look at long division. What we need to find out is whether children's errors are 'stable' enough for any such system to work in more than a trivial minority of cases. If they prove useful, the next question we need to address is whether the teaching methods envisaged in the last section will work for children who have already 'failed' to master the procedures identified.

## MISCONCEPTIONS

This species of error, one suspects, is the most important of all. It is also the least understood. Many students of children's maths learning have argued that attention to problems at the procedural level without a consideration of levels of conceptual understanding are unlikely to bear fruit. Though this may be the received wisdom (and I am not sure whether it is or not) – my own view is that the relation between conceptual understanding and procedural ability is more complex that such a view implies. It might be worth exploring this general issue in relation to research on literacy which, in my view, demonstrates the sort of complex interaction between 'top-down' and 'bottom-up' learning processes we are likely to find in mathematics learning

Common misconceptions in mathematics (I think we are able to identify a wide range of these) presumably have many origins. Personally, I think that two dimensions are particularly relevant. One emerges from the discontinuities between natural language and mathematical discourse and the other, as Skemp (1971) argued many years ago, from the non-ergonomical structure of mathematical symbol systems. Recent research which has served to identify common misconceptions provides considerable support for Skemp's thesis and raises uncomfortable questions about the need to re-think the lexicon of mathematical symbols.

In relation to language and communication, there is an important research agenda to be formulated, planned and executed. Problems of language and communication in mathematics teaching can be identified at many levels; letters, words, phrases, speech acts and discourse. A comparison of the process of communication in everyday discourse between adults and children and that which takes place in mathematics reveals many discontinuities which provide complex learning problems for children (Wood, 1988). Let me just hint at a few of these problems here. Examples are given by Hart and her colleagues (1981) of the use of pluri-functional words whose meaning in mathematical contexts is quite different to those implied in natural discourse (eg. prepositions). Similarly, Karmiloff-Smith (1979), in a detailed study of the way in which pluri-functional linguistic terms are used to make reference to sets and sub-sets (classification), illustrates the complexity of usage of 'simple' words, such as determiners and personal pronouns, which can be a source of misunderstanding in talk between adults and children. At another level of analysis, mathematical problems couched in words often violate, quite systematically, the meanings implied by what is said viewed in relation to natural discourse. Such observations raise some important issues concerning attempts to make mathematics 'relevant' by trying to teach it by means of examples drawn from 'everyday life'. Such attempts after relevance (and 'motivation') run the risk of compounding children's learning problems because the procedures involved in everyday solutions to such problems are quite different from those demanded for mathematical conceptualisation and solution.

This emphasis on the discontinuities between everyday uses of language and mathematical discourse underpins my own view; which is that we should seek to look in detail, from a multi-disciplinary perspective (mathematical, psychological, linguistic educational) at the social and linguistic practices involved in talk and text concerned with attempts to teach mathematics. Another set of issues, raised by Desforges for our seminar, concerns the 'typical' management and teaching styles found in classrooms. Basically, teachers do most of the talking and ask almost all

of the questions. Such discourse styles inhibit epistemic activity in children (Wood, 1986). They may or may not prove to be an inevitable consequence of traditional classroom practice. Charles Desforges will no doubt have much more to say about this issues.

## REPRESENTATION: DYNAMIC IMAGERY AND SYMBOLISM

There is a good case to be made for the proposition, put forward by Bruner and others, that attempts to teach the meanings of mathematical notation and procedures which are not grounded in enactive and iconic representation are misguided. New technology, particularly with the arrival of video-disc facilities, offers opportunities to provide children with dynamic, visual information. Will it prove possible to 'negotiate' the meanings of mathematical symbolism by exploiting these opportunities? Relevant to this issue is the current status of evidence relating to the impact of LOGO on children's learning and of the promises held out by Papert. My own reading of the relevant literature leads me to doubt the value of Papert's speculations about what children can learn in such contexts. I suspect that *instruction* is far more important than he envisaged. If, as I suspect will prove to be the case, the need for instruction and tutoring in such contexts is far more important than Papert allows, then we need to investigate both the ways in which teachers might best enter into a 'triangular' relationship with the learner and intelligent teaching systems and consider the design of intelligent tutoring systems designed to facilitate the development of dynamic, mathematical imagery. Here too, I would draw attention to one of the issues raised by Skemp. He suggests that gifted mathematicians are strong in dynamic, visual imagery and asks us to consider the possibility that recent developments in mathematics, which are more 'propositionally' oriented, might serve to inhibit the learner's perfection of systems of representation which form the foundations for innovation in mathematics. With the potential offered by new, intelligent teaching aids, we could turn this issue into a research agenda.

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# Changing Primary School Practice through Information Technology: Notes for a Research Agenda*

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IT is the latest in a long string of initiatives attempting to improve the quality of pupil learning experience in the primary school. The emphasis of these initiatives has been on the acquisition or nurturance of higher order intellectual skills. Previous initiatives have, by and large, failed to have much impact on prevailing practice. The powerful forces which sustain common classroom practice are now broadly understood. What is not understood is how to overcome them. In these notes I suggest areas of research necessary to help innovators design and sustain their programmes in the face of these forces. The focus is on research for teaching.

## INTRODUCTION

The work of pupils in primary schools is characterised by a predominance of teacher directed, routine practice tasks drawn mainly from commercial materials. Interactions are teacher dominated. The teacher directs discussion, does most of the talking, initiates, sustains and terminates most of the activities and demonstrates procedures to be used on task. Despite the salient trappings of practical work, tasks which challenge children's problem solving skills or which stand to enhance children's intellectual autonomy are rare (Bennett, et al., 1984; Galton, 1987; H.M.I., 1978).

Through a number of educational innovations, attempts have been made to improve the quality of pupils' learning experience. Special emphasis has been laid on the design of intellectually challenging activities. 'Language experience approaches to learning', 'new maths', 'new science', 'problem solving' and 'discovery learning' spring readily to mind. These initiatives have had a very short life. Whilst in their initial stages they are often treated with enthusiasm and show promise, once the external support for innovation is removed practices revert to tradition either quickly or very quickly, (Davies and McKnight, 1976). The materials of innovation often linger but they are absorbed into teachers' classroom management practices and used as part of the diet of practice tasks or maintaining activities. IT as an educational innovation looks, in the light of available classroom research, to be a not-so-special case of this pattern. Innovators enthuse and then go home. Teachers absorb materials in routine management. Children soldier on, their intellectual skills un-broadened and un-burdened (Johanson, 1987). We may safely conclude that educational innovation involving children in intellectually challenging work is difficult to sustain no matter how exciting initial effects appear to be (Porter, 1986). Even when teachers have been totally committed to desired changes, in-service programmes have had little effect in practice once support has been withdrawn (Duffy and Roehler, 1985).

It is becoming increasingly clear that regardless of other factors, teachers' practices may be constrained by a number of classroom processes and that teachers' behaviours, however unfortunate from the point of view of modern learning theorists, are adaptive to the conditions under which they work (Doyle, 1986a;

* For a more detailed account see Desforges and Cockburn, (1987).

Feiman-Nemser and Loden, 1986). If teaching practices are to be changed in order to facilitate the development of children's intellects, innovations will have to be designed in the light of an understanding of teachers' enduring working conditions.

## CLASSROOM CONDITIONS

Teachers are severely constrained in their practices. They are subject to increasing levels of accountability. Time is at a premium. The primary school has a large and ever increasing curriculum. Teachers are under pressure to cover a vast range of topics and concepts. They aspire to meet the range of intellectual attainments evinced by by the children in their classes. The curriculum materials at their disposal are well packaged and asthetically pleasing but of low quality in terms of instructional theory. The teacher organises all the material support for all aspects of activities from art through music to science. To classroom researchers it is perhaps small wonder that the most salient activity of teachers is that, 'they manage learners rather than learning' (Bloom, 1976). Establishing order in the sense of a coherent flow of activities, is a high priority for teachers (Doyle, 1986a).

Innovation demands a powerful understanding of these constraints. The most coherent and broad ranging model has characterised intellectual life in classrooms in information processing terms (Doyle, 1983). In this perspective there is an abundance of sources of information (books, exercises, displays, verbal and non-verbal behaviour) any one or combination of which may assume instructional significance. These sources, however, are not consistently reliable as instructional cues.

The classroom is inhabited by teachers and pupils each of whom has limited information processing capacity. Selections must be made from potential sources of information. Participants develop strategies to optimise selections to increase the predictability of classroom life. In this process many actions are made routine in order to free attentional capacity.

The central aspect of the environment which links teachers and pupils is the work which is presented for processing. Pupils accomplish tasks in a process of exchanges of performance for praise. The assessment system is thus the most salient source of information. The pupil tries to deliver what the teacher is predicted to reward. Pupils are not passive in this process. They have a number of strategies for getting teachers to be specific about what they want. Tasks which are open-ended or ambiguous are negotiated away. Whatever the intrinsic demands of tasks, they will always be interpreted in the terms of classroom information processing and the extant accountability system.

In this model any attempts to be innovative must face up to the constraints of the classroom in terms of the processes of curriculum management, accountability and communication (information processing). Intellectually challenging innovations, in this view, run the risk of either being routinised or marginalised. This is precisely their fate (Doyle, 1986b).

## SOME CLASSROOM IMPLICATIONS

It is left to others to contemplate teacher-proof curriculum and schooling without classrooms. It is assumed here that primary schooling will continue to be managed by teachers in schoolrooms.

Innovators, whether they are pushing a new subject, new activities or new resources, always have to face the problems of (a) how to find space in a crowded curriculum, (b) how to get the innovation started, (c) how to sustain it in serving the intended purposes.

*Curriculum Research*

Primary school curriculums are bursting at the seams. Teachers spend some time and not a little ingenuity organising knowledge and experience in themes or integrated studies. But the organising concepts are at best strained and frequently seem whimsical (Eggleston and Kerry, 1985).

If time is to be created for reflection in classrooms then rigorous and fundamental work on the organisation of knowledge in the primary curriculum is long overdue. We can anticipate that the proposed National Curriculum, couched in subject terms and framed by subject experts, will exacerbate rather than alleviate the problems of crowding. We are due a Woods Hole style initiative in which scientists in cognition and education work to reconceptualise the curriculum with more economy and power than present formulations can muster.

*Classroom Contexts*

Whatever the potential intellectual challenge of innovating educational resources, take-up is governed by opportunities as actually perceived in classrooms. Tasks are interpreted within the extant assessment procedures. These procedures may be altered or suspended for the period of an experiment or exploration or initiation. Once special conditions collapse, normal service resumes and work with innovatory materials becomes part of predictably assessable work or is marginalised. We need to know a lot more about how children interpret classroom tasks within the assessment structure of the classroom. We need to know more about learners' strategies for making work routine if we are to protect intellectually challenging innovations from the same black hole. Alternatively, or additionally, we need to explore different forms of assessment structures with potential for sustaining challenging experiences.

*Time to Learn*

The more reflective we require learners to be the more time it takes to cover concepts. If teachers are ... weaned away from 'coverage' there has to be some valid foundation on which time is allocated to the proper treatment of concepts. Yet there is hardly any research on time to learn under various conditions. The research community has ignored this central feature of classroom life.

*Teaching Cultures*

Innovations will always be adapted to the cultures in which they are sited. Innovators need an empirically well based model of that culture with specific reference to the response to change. There is very little empirical work appropriate to framing such a model for teaching (Feiman-Nemser and Floden, 1986). We need to know what is in innovation for the mass of teachers once Hawthorn effects subside. What attitudes and beliefs do teachers have that would make specific innovations appealing or unattractive? What can an innovation offer teachers that they can be persuaded to need? More broadly, how do experienced teachers learn and develop professionally?

Models of teacher development are thin on the ground, not empirically well based and not associated with successful implementation (Guskey, 1986). It has been proposed that teachers' central professional interest is in overt manifestations of pupil progress. If progress is clearly evident associated practices are valued. If this proposal proved valid and became part of an empirically well established model of professional development, the onus would be on innovators to provide teachers rapidly with evidence that their innovations fostered progress. This in turn creates a need for research on ways of recognising and representing learning progress in ways which are infinitely more subtle and sophisticated than those currently available

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# Comments and Reflections:

## Rapporteur 1

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### OVERVIEW

My role at the seminar was to summarise and synthesise the discussion that took place in one of the two sub-groups that were formed early in the seminar. The major issues for us were those that arose out of the first part of our agenda, in which we considered the nature and problems of science and maths education *per se*, prior to looking more specifically at IT issues. In preparing some comments for a wider readership, it is necessary to impose some specious order upon the discussion, and perspectives and reflections of my own. I apologise to the other participants for the many ideas that I may have failed to note, to understand or to integrate into this account.

Our discussion centred upon a set of related issues, the major of which were:

Children's naive conceptions of the world,
contrasted with school science and maths.
Issues of function and purpose.
Context and content specificity of learning,
versus generalised concepts and skills.
Error correction: its nature and inculcation.
The nature and importance of explanation in understanding.
Science and mathematics as kinds of discourse.
The relationship between practical experience and scientific discourse.

I shall attempt to take each of these in turn, though they cannot be kept strictly apart. And hopefully, since we are looking forward to the creation of research agendas, the fact that we are left with questions rather than answers will not be disappointing.

### NAIVE CONCEPTIONS VERSUS SCHOOL SCIENCE AND MATHS

It was recognised that research has begun to investigate the nature and extent of children's pre-school (and enduring) "naive" or "spontaneous" conceptions of the world, the ways in which children understand, explain or account for physical phenomena outside the formal systems offered by school science and mathematics. Clearly there is a need to understand the origins of these naive conceptions, and their relationship to formal systems and to the process of education. Some relevant work was cited in the written contributions to the seminar, by Ros Driver and Joan Soloman, in particular. It was noted that we may not have to concern ourselves with how pupils' naive conceptions might be transformed into formal/scientific ones. Common sense understandings can be powerful and useful, and may continue alongside their scientific counterparts as alternative modes of thought and explanation. We need to further our understanding of the relationships between these different modes, and discover how far they are in conflict, or are complementary, or again, mutually beneficial. Perhaps it would be useful to consider them as alternative explanatory discourses, rather than as perceptually-derived mental models. That is a possibility that may make more sense as I proceed with the account.

Some dissatisfaction was felt both with the Piagetian, and with the information-processing approaches to this issue (represented in the main by American research, eg. Susan Carey's (1985) work), in which naive conceptions are seen as essentially the product of individual perception and action, and of consequent mental model-building. Indeed, the terms 'spontaneous', 'intuitive' and 'naive' do seem to carry the unfortunate implication that only at school do children enter a world of cultural and shared understandings. Before that, at home and at play, they are, presumably, self-contained little individuals striving to make sense of their individual experience, whose achieved "common sense" understandings are common not for cultural or communicative reasons, but for "natural" ones – universals of mind, of perception and action, perhaps. The alternative possibility, that common sense explanation is acquired along with a pre-school common language and culture, needs to be taken seriously.

As well as studying children's intuitive or commonsense understandings, we need also to take account of the nature and practice of science itself. The question was raised, what do we want children to achieve? Are they to become scientists, to think and work like scientists do, or are they merely to come to understand the products of science – the received wisdom, rather than the process of invention and discovery? And what, in any case, is the relationship between the "official" story of science, the scientific method, the laboratory report, the formalisation and testing of theory, etc., and the actual working practices and thinking of scientists? Do we teach science as it is practised, or as it is written up and, some would claim, mythologised? There is plenty of evidence of the capacity both of scientists and of school pupils to override the evidence of "discovery" in favour of a fondly held explanation.

## FUNCTIONALITY: WHAT IS IT ALL FOR?

Making progress in research on science and maths education, and on the introduction of information technologies into that educational process, clearly requires that we deal with the relationship between the understandings that children bring to school, and the understandings that the curriculum requires that they achieve. One of the sub-issues that needs to be addressed is the functional one: what is the purpose or pay-off for pupils of knowing about science, or of achieving expertise in mathematics? Both systems can be used to solve practical problems, as well as problems internal to each system. The view was expressed that children may be unwilling to alter or add to their ready-made models and assumptions about the world (or discursive explanations of it), if the new knowledge is not seen to be applicable or useful, or relevant to their interests. it was noted also, that these "interests" need not be of a practical, everyday character. Indeed, some of the notions that pupils find the most fascinating are those that deal with the weird and wonderful – black holes, the possibility of life on other planets, and such.

People, whether "expert" in some domain or not, often have difficulty in articulating the basis of what they know. This is especially the case with knowledge in which people feel at home, comfortable and in control of it, knowledge which is "personal" (in Polanyi's sense), thoroughly internalised or "owned" While the superficial content of that knowledge might be easily expressed, the difficulty is in communicating the process, origins and context of thought that would make it intelligible to others. It is easy for experts, teachers included, to underestimate the contextual basis of their knowledge, and equally, the different contextual basis of

their pupils' understanding. This is a fundamental theoretical and research issue both for education in general, and also for expert systems design (and therefore also, for its educational application). We need to take account of the contextual and functional aspects of educational knowledge for there to be any progress in our understanding of how teachers and pupils achieve (or fail to achieve) an educational meeting of minds.

## CONTEXT AND CONTENT SPECIFICITY

In all learning contexts, we meet the perennial problem of transfer or generalisation, of the extent to which learning remains embedded within a particular domain of talk and activity, or else generalises to new contexts and domains. To some extent, this is involved with the issues of "ownership" also; one feels at home in a set of concepts, or an explanatory framework, when one is able to take control of it and apply it to altered or new circumstances. Much recent research has stressed the context or domain specificity of learning, and of the results of introducing new intellectual technologies (a seminal study is Sylvia Scribner and Michael Cole's cross-cultural work on the cognitive consequences of literacy, in The Psychology of Literacy, 1981).

It is clear that we cannot expect to introduce any new technology into the educational process and expect it *ipso facto* to lead to generalised intellectual effects. The point is that we need to examine the conditions under which conceptual learning becomes "owned" and generalised, in the sense of being *applicable to many contexts of use*, rather than merely "abstract", or in any sense independent (or "disembedded") from contexts of use. There are currently active developments in this area, notably the Vygotsky-influenced work of Michael Cole* and his colleagues who are concerned with the notion of "scientific concepts" in the sense of those that we can consciously reflect upon and talk about, and which develop out of practical contexts of shared talk and activity. But this is my own rather than the group's particular interest, so I shall not push the idea further here.

## ERRORS AND ERROR CORRECTION

It is often precisely when people generalise learning to new contexts or problems that false understandings are revealed. Children's errors may be rule-governed, rather than random, and this again is a revealing indication of the basis of their understanding. Sometimes misunderstandings are of a fundamental sort, and yet do not reveal themselves easily. This can occur when pupils do not share with teachers the same conception of the nature and purpose of what they are doing, of the special nature and requirements of school tasks, including simple arithmetic: that is, of the specific and general educational "ground rules". These ground rules are usually implicit in classroom tasks, not overtly communicated, and indeed, often not consciously known by the teacher.

The notion of "error" is not as mechanical and straightforward as the term implies. It is not always the same thing as when we write bugged computer programs and have to make them work. It often involves a social dimension, and is part of the joint nature of educational understanding; children "realise" that they are wrong frequently because the teachers tells them so. This is part of the reason why

* Michael Cole and his colleagues present accounts of their work in the Quarterly Newsletter of the Laboratory for Comparative Human Cognition, University of California at San Diego.

efforts to foster self-correction are so problematical, outside of limited domains, and yet ability at self-correction is one of the favoured fruits anticipated of classroom IT. To some extent we have a chicken-and-egg problem, in that error checking is itself dependent on expertise. But that is a problem only for self-contained individuals. Again, as we have stressed, individuals are good at ignoring counter-evidence, until confronted with it by another person in open disagreement or argument. If information technology (an expert system, say) is to foster error correction, it will have to be able to substitute for, or play second fiddle to, the role of teacher as critic and rhetorician to the child's understandings – it would not be enough that the system merely knows and gives access to the received wisdom. One possibly fruitful avenue is to organise occasions for pupils to correct the work of others, and to explicate the basis for doing so. This can have additional pay-offs with regard to revealing the "ground rules" sorts of assumptions, the pupils' conceptions of the nature, purpose and criteria of school work, as well as in fostering the sorts of metacognitive awareness that is basic to "scientific concepts". There is also a body of opinion that favours the effects of dissonance and cognitive conflicts that such practises might engender.

Let me put a more general slant on this. The notion that internal/mental conflicts between assumption and discovery, theory and evidence, truth and error, may in fact find themselves realised as external, social conflicts or disagreements between people, points us towards a more social, discursive notion of education than the one that cognitive science and IT might at first entertain. The introduction of IT into classrooms is not merely the introduction of new ergonomically designed tools into the cognitions and activities of individual minds or individual learners. It has to be done in a manner that is congruent with the social basis of the educational process.

## EXPLANATION

One of the characterisations of modern educational practice that gave us some cause for concern was what appears to be a pervasive over-emphasis upon practical and procedural rules and mnemonics (for example, in the application of formulae in physics), at the expense of discussing the underlying principles of which those rules are a particular expression. As with the implicit bases of educational knowledge and practice, even the more explicit teaching often remains undiscussed and unexplained, so that children may be left unsure of both the underlying explanatory principles and even of what would constitute an adequate explanation. This was felt to be due in part to the prevalence in modern schooling of a particular pedagogical philosophy, with its recognisable psychological underpinnings (such as Piagetian theory), that has emphasised inductive learning through direct experience and discovery.

Recent studies (including those by some of us at the seminar) have argued for the importance of achieving explicit, verbally communicated understandings. Again, open discussion and argument in the classroom would seem to offer the simplest approach, with pupils being required to explain things for and to each other, and to discuss the limitations of each other's explanations. But we were not concerned directly, in the seminar discussion, with practical pegagogical solutions. The implication for the introduction of IT would again appear to be that limited results, misunderstandings and dissatisfaction are likely to ensue from any notion that children can learn for themselves what we want them to learn, *merely* from direct hands-on experience.

There are some developments, in the recent American psychology of conceptual growth in children, which emphasise an individualistic process of developmental changes in domain-specific "theorising". This is best exemplified by Susan Carey's work (1985). But the emphasis even there is upon word meanings and conceptual extensions of word meanings – that "racoons" are understood to have had parents that were racoons, complete with internal organs, stomachs, etc., and that conceptual development includes the acquisition of accepted scientific explanatory frameworks (such as, for animals like racoons, an evolutionary basis for zoological classification). This emphasis on conceptual word meanings would be amenable to reinterpretation from a social-discursive perspective, in which we would seek not only a cultural, communication-based conception of education, but also, in Vygotsky's spirit, an educational or instructional basis for our understanding of conceptual development itself. It is that sort of approach to conceptual development and to classroom teaching and learning that will be best equipped to deal with the introduction of new symbolic and communicational media into schools, if only because its prime concerns are precisely with symbolic media, conceptual development and its basis in instruction.

## SCIENCE AND MATHEMATICS AS DISCOURSES

Both science and mathematics can be considered as discourses, both intrinsically ("symbol systems with a syntax", as one of us put it), and also in the sense that they are verbally explained and communicated. The establishment of scientific knowledge is a collective, communicative enterprise, in which public scrutiny of methods and results, communication of findings, argument and alternative theorising, conventions of sound practice, and so on, are its everyday currency. Mathematics also depends upon the establishment of conventional symbolic representations, and the acceptance in the community of mathematicians of agreed criteria of validity and application. School mathematics especially is noted for its pedagogic use of verbal formulations and "concrete" contexts (metaphors such as "add", "take away", "makes", and various pseudo-narratives of the sort, "if it takes four men to dig a hole ..." etc.), these being discourses with their own unique rules of interpretation to help understanding, or equally likely, to trap the uninitiated. The point of stressing these discursive aspects of science and mathematics is that they often go unnoticed. Mathematical conventions are transparent to the expert, but may be opaque to the novice. The truths of mathematics and of science are not simply there to be seen, experienced or induced from experience. And to compound the problem, teachers themselves may be unaware of, and unable to explicate, the discursive conventions. We have to decide what it is we are trying to achieve. Do we want pupils to be competent practitioners in the creation of knowledge, or well drilled consumers of a pre-ordained wisdom? Is there in fact much of a difference?

Part of the problem with school science, already mentioned here, is the probability that it projects an idealised version of science. As many of us have observed, there is a tension in school science, between what an experiment or observation is *supposed* to show, and what actually happens in the classroom (see for example, Driver, The Pupil as Scientist? (1983), and Edwards and Mercer, Common Knowledge (1987). Usually, under the teacher's guidance, the official version of events prevails. This is ironic and puzzling from the point of view adopted by inductivist learning theorists. But interestingly, it is a tension that has a parallel in the "real" world of science, between what scientists actually do and think, and the story they tell of the process when it comes to writing about "method", or

communicating the results of experimental studies. Sociologists of science, such as Michael Mulkay, Nigel Gilbert (see Opening Pandora's Box (1984), and H.M. Collins (in Changing Order (1985), have provided a wealth of demonstrations of how science itself, its methods and principles (such as replicability), are social and discursive productions with similar tensions to those that we can identify in scientific pedagogy. Indeed, we need perhaps to recast the seminar's avowed aims in the light of such considerations; they may have a good deal to do with the fact that in coming together to discuss "what we know" about the development of scientific and mathematical concepts, prior to knowing how best to proceed with classroom IT, we found ourselves engaged for most of the time in trying to sort out what our preliminary understanding actually was!

## EXPERIENCE AND DISCOURSE

Having sought to define science and mathematics as discourses, and having been critical of inductivist notions of classroom learning and conceptual development, one of our major research tasks must be to examine the developmental relationship between experience and conceptual discourses. We need to study how they come together, and it is probable that qualitative research that is based upon an analysis of situated discourse will be important. There is, in any case, a methodological advantage to researching visible pedagogic discourse, rather than struggling to make inferences about children's mental models and processes. Indeed, this sort of research is needed not only so that the introduction of IT might be better informed, but also, as an approach to examining the educational uses of IT itself.

In looking at the relationship between the perceptually based and the social-discursive foundations of conceptual understanding, we need to keep two senses of the social in mind. Cognitions can be socially based developmentally, in that they can be seen to originate out of communication and symbolic representations: and they can be social in that they *remain* embedded in social contexts, in communicative shared understandings, rather than merely abstracted into the minds of individuals. It is this latter sense of the social nature of cognition that is least catered for by current cognitive science.

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# Comments and Reflections

## Rapporteur 2

*Paul Light, Centre for Human Development and Learning, The Open University*

### INTRODUCTION

One of the points of consensus at the seminar concerned the importance of recognising that Science and Maths are *social* activities, in that they involve establishing agreements about what constitutes explanation or proof, agreements about criteria of validation and so on. They also frequently involve *disagreements* and are characteristically argumentative activities. All these things could certainly be said about this seminar too.

The very considerable difference in research 'style' and approach between educationalists and psychologists were apparent at times, but there proved to be a number of important areas of common concern to both. Perhaps the most obvious was the issue of the domain specificity of developing knowledge, which in one way or another permeated much of our discussion. The broad conception of cognitive development as mediated by socially constructed *discourse* seemed to me to be very central, and to offer a bridge between the current developmental psychological literature and the literature on science and maths education. By the end of the meeting there as wide agreement that the necessary conditions for interdisciplinary research in this area (involving the groups represented at the meeting together with teachers) were fully met, and that steps to facilitate collaborative teamwork should be taken. I have tried to indicate some of the suggested foci for such work under a number of headings.

### SOME BROAD RESEARCH AREAS

(a) *Transposition didactique*: work on the relationship of Science and Maths on the one hand and teaching on the other. How Science and Maths are changed in the process of being taught, and how computers alter (or could alter) the nature of this transposition.

(b) *Work at the teacher-pupil level*: focussed on the nature of pedagogic discourse in science and maths education, and again the way in which IT can alter this discourse.

(c) *Work at the system level*: looking at the dynamics of change (and resistance to change) in maths and science curricula and more generally in classrooms and schools.

### MORE SPECIFIC TOPICS FOR REVIEW AND FURTHER RESEARCH

(a) *Commonsense, intuitive knowledge, pragmatically based reasoning:* these and other terms catch at a rich vein of contemporary work. For example, in AI there is work on commonsense thinking in the context of intelligent systems. In the field of science and maths education there is work on children's naive or 'alternative' conceptions. In developmental psychology there is work on 'natural logics' and pragmatic schemas, as well as work on mathematical reasoning inside and outside of the classroom. There is a great deal of common ground here but the literatures tend to develop separately. There might be a case for trying to get some of them pulled together through a short-term consultancy, and further work in this area could be very valuable.

(b) *Errors*: here again we see AI/Cognitive Science work on 'debugging', work in the area of maths education on errors and error correction and on metacognitions concerning errors and checking. \this is another very lively area where some more imaginative work could be done with advantage.

(c) *Child-child and child-computer interaction*: we need to take what we know about social interaction and learning, group-based problem-solving, 'marquage sociale' etc., and think about child-computer interaction in this context. This might, for example, involve consideration of the status of the computer as a 'psychological entity' for the child, or of the way software-based trace, help or interface facilities are used by individuals and groups.

(d) *Reality and simulation*: a variety of more or less closely related issues arose in this area. Screen representations of physical systems stand somewhere between 'the real' and a formalised symbolic representation of that reality. This may be a strength (bridging from the former towards the latter) or a weakness (losing important features of interaction with the physical system itself). On the positive side. it was suggested that dynamics and transformational imagery may play a particularly important role in scientific and mathematical reasoning and the potentialities of IT for *representing* change and transformation may be particularly significant. In various ways, though, the status ascribed by the child to the screen representation may be problematic, not least because it is so easy to simulate 'alternative realities'. Such issues concerning simulations merit further study.

(e) It was noted that developmental psychologists. especially in France and the USA, have recently begun to take considerable research interest in very *particular* processes of mathematical/scientific understanding, especially arithmetic, but that much of this work was not readily available. Also, developmental work in other areas (eg. on children's economic concepts) is relevant to mathematical education but is unlikely to be known to maths educators. There is room for a useful pulling together of the contemporary developmental literature most relevant to maths and science education.

## AREAS FOR DEVELOPMENT THROUGH FURTHER SEMINARS – WORKSHOPS OR OTHER ACTIVITIES

A suggestion which found considerable favour was that maths and science educators might usefully get together with interested psychologists to look more closely at what they consider to be 'good practice'. The agenda might encompass consideration of what 'goods' such practice might be expected to deliver in terms of learning, and what kinds of investigation might help to establish whether it does so. The development of research tools appropriate to this area was considered vital.

We need to look at the claims made, for instance by proponents of an investigative curriculum, or by proponents of direct instruction, and consider how different outcomes (in terms of children's mathematical/scientific attitudes or understanding) could be appraised. There is as yet very little *empirical* investigation of such issues as the value of activity-based small group work, or of the 'elicitation' method of teacher questioning.

In general, there was a feeling that *methods* should be kept high on the agenda. Longitudinal methods had an important part to play – for example looking at the way children's intuitive concepts about the physical world develop and change as they progress through schooling. Also, there is a place for research which takes a broader look as a range of aspects of mathematical and scientific reasoning and understanding (and beyond this to literacy, etc.) in the same children, countering the very narrow focus of most present research. There might be considerable merit in collaboration with other European countries in developing such studies, but we should be looking for something adventurous and theory-based rather than vast ponderous data-gathering enterprises.

# Comments and Reflections

## Rapporteur 3

*Michael Eraut, Education Development Building, University of Sussex*

### AN OUTLINE RESEARCH AGENDA

*The curriculum of the future*

What sort of mathematics will be most important in 10 years time when information technology has become much more pervasive? Presumably some things should be dropped and be replaced by others.

What kind of tasks should constitute the curriculum, and can curriculum decision-making be better informed by more study of how curriculum knowledge is used in the world? There is a need for further study of topics like estimation and modelling.

What new curriculum possibilities will be opened up by the use of information technology? The curriculum potential of innovations such as microworlds needs careful analysis. So also do expert systems.

*Metacognition*

The link between metacognition and transfer.
Classroom problems in implementing metacognitive strategies.
The use of computers in developing metacognition.

*Evaluation of teaching methods*

How much learning is going on, of what kind, and what are the optimal conditions during:

- activity-based learning;
- group-work;
- simulations.

*Computer assisted learning*

Two major research needs were in:

- human-computer interaction;
- analysis and evaluation of materials.

*The change process*

There was a need to study the methods and real costs of:

- proper field-testing of new materials;
- disseminating new ideas;
- INSET of sufficient quality and quantity to
- achieve stated goals.

*Pupil attitudes*

How did the use of IT affect pupil attitudes toward the subject and their willingness to take it further.

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